WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

TITLE: Sage Creek Instream Flow Studies

PROJECT: FX-GR-3SF-511

AUTHOR: Paul D Dey and Thomas C. Annear

DATE: November 1999

ABSTRACT

Studies conducted during 1997 determined instream flows necessary for maintaining Colorado River cutthroat trout (CRC) habitat and populations. Physical Habitat Simulation (PHABSIM), the Habitat Quality Index (HQI), and the Habitat Retention Method were used in determining instream flow water right recommendations of: October 1 - April 30 = 1.1 cfs, May 1 - June 30 = 3.9, and July 1 - September 30 = 1.1 cfs.

INTRODUCTION

Wyoming's instream flow law (W.S.41-3-1001) defines the Wyoming Game and Fish Department's (WGFD) role in identifying instream flow levels necessary to maintain important fisheries. According to the law, unappropriated flowing water "may be appropriated for instream flows to maintain or improve existing fisheries..." (W.S.41-3-1001(b)). WGFD instream flow recommendations must be for specific stream segments and seasons. These recommendations are incorporated into an instream flow water right application and, as provided by statute, may become an instream flow water right held by the state of Wyoming. This process ensures that adequate stream flow is protected when it is available in priority so that important fisheries will persist.

Since the law was passed in 1986 and through 1997, 76 instream flow water right applications have been filed, 7 approved by the state engineer, and 2 formally adjudicated. Initially, efforts focused on WGFD class 1 and 2 waters, which are highly productive and provide popular recreational opportunities. More recently, efforts have shifted toward small headwater streams supporting native cutthroat trout.

Wyoming has historic ranges for Bonneville cutthroat trout (*Oncorhynchus clarki utah,* sometimes locally referred to as "Bear River" cutthroat trout), Colorado River cutthroat trout (*O.clarki pleuriticus*), and Yellowstone cutthroat trout (*O.clarki bouvieri*). A variant of Yellowstone cutthroat trout, the Snake River cutthroat trout, also occurs in the northwest portion of the state. Since the early 1990s, instream flow studies have been done on many stream segments throughout the native range of Bonneville and Colorado River cutthroat trout. This report includes results and recommendations from studies on Sage Creek, a Colorado River cutthroat trout stream. Wyoming's instream flow law (W.S.41-3-1001) defines the Wyoming Game and Fish Department's (WGFD) role in identifying instream flow levels necessary to maintain important fisheries. According to the law, unappropriated flowing water "may be appropriated for instream flows to maintain or improve existing fisheries..." (W.S.41-3-1001(b)). WGFD instream flow recommendations must be for specific stream segments and seasons. These recommendations are incorporated into an instream flow water right application and, as provided by statute, may become an instream flow water right held by the state of Wyoming. This process ensures that adequate stream flow is protected so that important fisheries will persist.

The historic distribution and conservation status of Colorado River cutthroat trout is reviewed in Young (1996) and Nesler et al. (1999). In Wyoming, historic range includes streams tributary to the Green River: the Little Snake River drainage on the west side of the Sierra Madre mountains, Green River tributaries draining the east face of the Wyoming Range mountains, the Blacks Fork River and its tributaries arising in the Uinta mountains, and a few tributaries that flow directly into the Green River from the east. Prior to 1997, instream flow studies were conducted in the major drainages of the Wyoming Range and Sierra Madre mountains. During 1997, additional studies were performed in remaining streams such as Sage Creek, a tributary to the Blacks Fork River.

A conservation plan was developed by Wyoming, Colorado, and Utah state wildlife agencies, in coordination with the U.S. Fish and Wildlife Service, to guide conservation efforts in the tri-state area through three primary activities: protecting existing and restored ecosystems, restoring degraded ecosystems, and planning (Nesler et al. 1999). The process of acquiring and maintaining appropriate instream flows is listed as a strategy for restoration. Obtaining instream flow water rights to be held by the state of Wyoming will provide assurance that available water will be reserved when it is available in priority for providing CRC habitat. Such efforts do not increase habitat from present levels or ensure that adequate habitat is available; instead, they act to avoid future water depletions up to the limits established by instream flow water rights. Instream flow water right acquisition is just one step in a comprehensive process of protecting and conserving native cutthroat trout habitat and populations.

Study objectives were to 1) investigate the relationship between discharge and physical habitat quantity and quality for Colorado River cutthroat trout in Sage Creek and, 2) determine an instream flow regime that will help maintain the Sage Creek Colorado River cutthroat trout fishery.

METHODS

Study Area

Sage Creek is located in southwest Wyoming in Uinta County, southeast of Mountain View. The headwaters are located in Utah and the stream flows generally north on Wasatch National Forest land in Wyoming before entering private lands and eventually flowing into Cottonwood Creek (Figures 1-2). The upper boundary of the proposed instream flow segment is at about elevation 9,050 feet and is the boundary between sections 12 and 13 of Range 115W, Township 12N. This point marks a location where the creek is fully formed from its primary springs. The downstream boundary for the proposed instream flow segment is the Forest Service boundary in section 31 of Range 114W, Township 13N. at an elevation of about 8,340 feet.

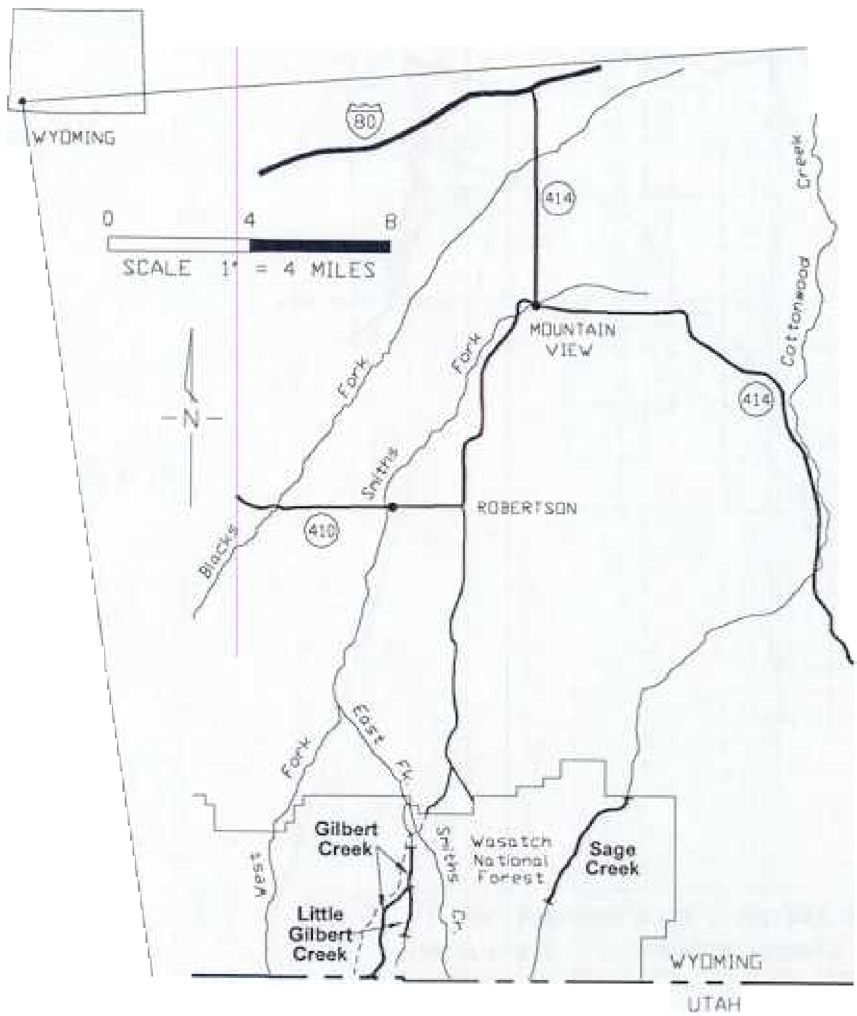

Figure 1. Sage creek instream flow segment and general vicinity.

Sage Creek originates from springs and small headwater tributaries on the eastern end of the Uinta Mountains with elevations of over 9,000 feet in the basin. Watershed climate is montane with 14-16 inches of annual precipitation in the headwaters and lesser amounts at lower elevations. Snowmelt run-off typically occurs in May and early June while springs sustain baseflow the rest of the year. Stream aspect is north and east facing throughout the proposed instream flow segment. The stream valley is moderately steep and colluvial and conforms to Rosgen and Silvey (1998) valley type II. Under the same classification scheme, stream type is largely B3 reflecting a gradient of 2-4% and predominantly cobble substrates.

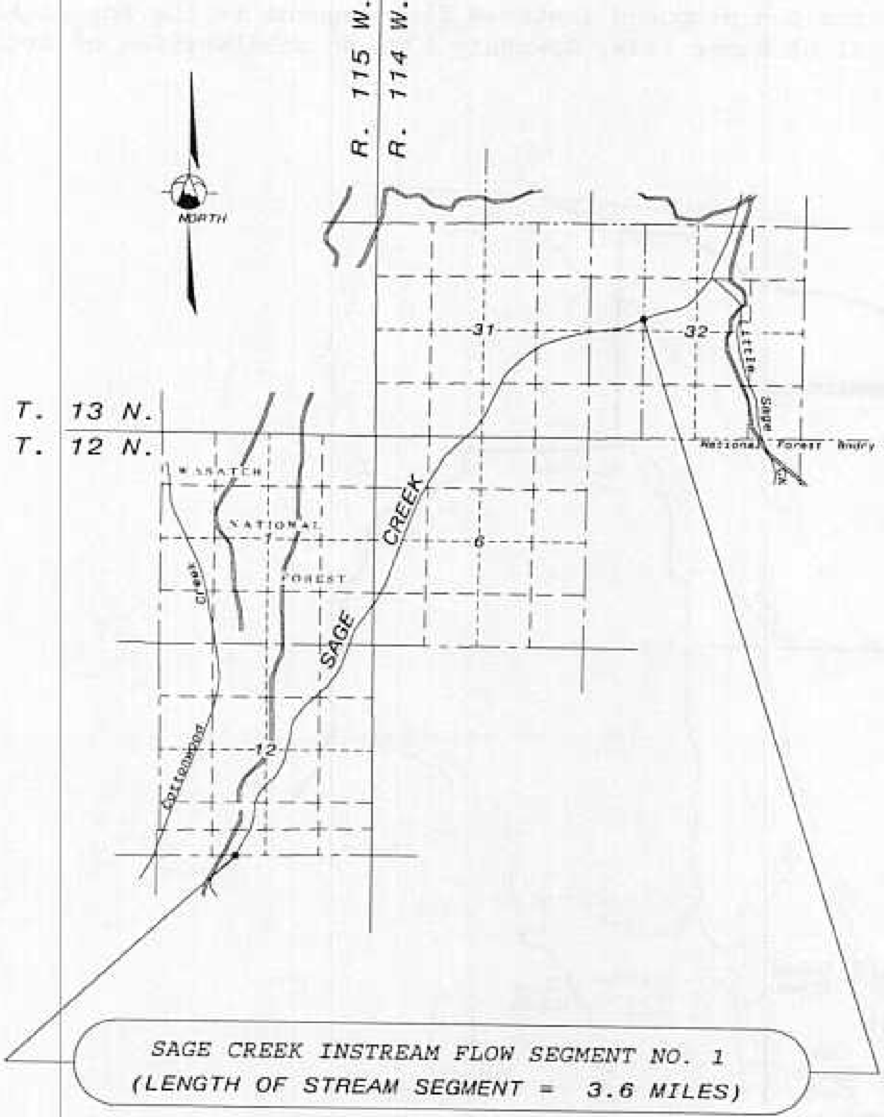

Figure 2. Detailed schematic of the instream flow segment and land ownership.

Upland vegetation is largely lodgepole pine (*Pinus contorta*) with some scattered aspen (*Tremuloides spp.*). More often, where aspen occurs it is mixed with lodgepole pine. Riparian woody species include lodgepole pine and aspen along with a few douglas fir (*Pseudotsuga menziesii*). Relatively uncommon low gradient benches, perhaps formed from historical beaver dams, support sedge (*Carix spp.*) and willow (*Salix spp.*) growth.

The watershed experiences moderate cattle grazing while timber harvest has occurred historically. The basin may be hydrologically disrupted from a natural pattern as runoff occurs rapidly and overland flow is common. This may be due to an excess of non-serotinous lodgepole pine (due to fire suppression) which create xeric conditions, decrease vegetative ground cover and thus promote overland flow (Kevin Spence, personal communication).

Beaver are often important for maintaining watershed integrity and function in streams and Sage Creek is likely no exception. Records indicate a colony was active in the mid 1990's. High flows in 1998 removed most dams and the extent of recolonization is unknown. For trout fisheries, beaver presence in a drainage provides benefits such as stabilized banks, reduced sediment sources from banks, and deep pools for overwintering trout.

Fisheries

In addition to CRC, mottled sculpin (*Cottus bairdi*) are native to the Sage Creek drainage. The stocking history for Sage Creek includes brook trout (*Salvelinus fontinalis*) in 1941 and Snake River strain cutthroat trout as late as 1958 and 1960. The collection of predominantly large spotted resident trout during sampling in the 1980's is evidence that the CRC gene pool is intact (Keith 1997). Genetically pure CRC were stocked several times during the 1990's at a level of about 2,000 fish annually to bolster purity. A gabion barrier and eight habitat improvement structures were constructed in 1989 cooperatively with Trout Unlimited and the Forest Service. The barrier acts to eliminate upstream movement of Snake River cutthroat trout and thereby protect the purity of upstream CRC. The habitat improvement devices provide adult cover - a habitat feature largely lacking throughout the instream flow segment.

The Green River fish management crew collected population data from two stations on the Forest and an additional two downstream stations several times during the 1980's and 1990's (Keith 1997). CRC abundance was generally good, particularly at the site nearest the barrier where density varied between 186 and 323 trout per mile. A population estimate conducted at the instream flow study site in 1997 showed a density of 263 trout per mile (42 lbs/acre). Trout ranged between 3.9 and 10 inches in length.

In a western Oregon stream studied for 11 years, density of age 0 cutthroat trout (fry, <2 inches) varied from 8 to 38 per 100 m^2 and density of age 1 cutthroat trout (juveniles, 4-4.5 inches) ranged from 16 to 34 per 100 m^2 (House 1995). In this example, population fluctuations occurred despite the fact that habitat conditions were not degraded and appeared to be relatively stable. The author suggested that small changes in peak winter flows between years would have accounted for shifts in overwinter survival between age-classes.

Similar population fluctuations occur in Sand Creek, a Crook County, Wyoming stream that experiences relatively little discharge variation (Mueller 1987). Sand Creek brown trout population density ranged from 646 trout/mile to 4,060 trout/mile in a three-year period. Biomass estimates for the same period ranged between 48 and 142 pounds per acre.

These two examples illustrate that trout populations, particularly in small mountain streams, are expected to fluctuate. Long-term trout population maintenance depends on periodic strong year classes produced in good flow years. Without benefit of periodic favorable flows, populations might decline or disappear. The WGFD instream flow strategy recognizes the inherent variability of trout populations and thus defines the "existing fishery" as a dynamic feature. Instream flow recommendations are based on a goal of maintaining habitat conditions that provide the opportunity for trout numbers to fluctuate within existing natural levels.

Habitat Modeling

A representative study site was located at Township 13N, Range 114W, Section 32, NW1/4 on May 20, 1997 (Figure 1). The site contained trout cover associated with boulders and lateral scour pools. Ten transects were distributed among pool, fast riffle, shallow riffle, and run habitat types (Appendix 1). Data for calibrating simulations were collected between May 20 and August 26, 1997 (Table 1).

Table 1 Dates and discharges Sage Creek instream flow data were collected in 1997.

Date	Discharge (cfs)
May 20	2.5
June 3	2.1
July 24	1.2
August 26	1.1

Determining critical trout life stages (fry, juvenile, adult, etc.) for a particular time period is necessary for developing flow recommendations. Critical life stages are those most sensitive to environmental stresses. Annual population integrity is sustained by providing adequate flow for critical life stages. In many cases, trout populations are constrained by spawning and young (fry and juvenile) life stage habitat "bottlenecks" (Nehring and Anderson 1993). Our general approach includes ensuring that adequate flows are provided to maintain spawning habitat in the spring was well as juvenile and adult habitat throughout the year (Table 2).

Table 2 Colorado River cutthroat trout life stages and months considered in Sage Creek instream flow recommendations. Numbers indicate method used to determine flow requirements

Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult							1	1	1			
Spawning					2	2						
All	3	3	3	3	3	3	3	3	3	3	3	3

1 = Habitat Quality Index; 2 = PHABSIM 3 = Habitat Retention

Habitat Retention Method

A Habitat Retention method (Nehring 1979; Annear and Conder 1984) was used to identify a maintenance flow by analyzing data from hydraulic control riffle transects. A maintenance flow is defined as the continuous flow required to maintain specific hydraulic criteria in stream riffles. Maintaining criteria in riffles at all times of year when flows are available in priority ensures that habitat is also maintained in other habitat types such as runs or pools (Nehring 1979). In addition, maintenance of identified flow levels may facilitate passage between habitat types for all trout life stages and maintain adequate benthic invertebrate survival.

A maintenance flow is realized at the discharge for which any two of the three criteria in Table 3 are met for all riffle transects in a study area. The instream flow recommendations from the Habitat Retention method are applicable year round except when higher instream flows are required to meet other fishery management purposes (Table 2).

Table 3. Hydraulic criteria for determining maintenance flow with the Habitat Retention method.

Category	Criteria
Mean Depth (ft)	Top Width[a] X 0.01
Mean Velocity (ft/s)	1.00
Percent Wetted Perimeter[b]	50

a - At average daily flow or mean depth = 0.20, whichever is greater
b - Percent of bank full wetted perimeter

Simulation tools and calibration techniques used for hydraulic simulation in PHABSIM (Physical Habitat Simulation) are also used with this technique. The PHABSIM method uses empirical relationships between physical variables (depth, velocity, and substrate) and suitability for fish to derive weighted usable area (WUA; suitable ft^2 per 1,000 ft of stream length) at various flows. The habitat retention method involves analysis of hydraulic characteristics at control riffles. The AVPERM model within the PHABSIM methodology is used to simulate cross section depth, wetted perimeter and velocity for a range of flows. The flow that maintains 2 out of 3 criteria for all three transects is then identified.

Habitat Quality Index

The Habitat Quality Index (HQI; Binns and Eiserman 1979; Binns 1982) was used to determine trout habitat levels over a range of late summer flow conditions. Most of the annual trout production in mountain streams occurs during the late summer, following peak runoff, when longer days and warmer water temperatures stimulate growth at all trophic levels. The HQI was developed by the WGFD to measure trout production in terms of habitat. It has been reliably used in Wyoming for habitat gain or loss assessment associated with instream flow regime changes. The HQI model includes nine attributes addressing biological, chemical, and physical aspects of trout habitat. Results are expressed in trout

Habitat Units (HUs), where one HU is defined as the amount of habitat quality that will support about 1 pound of trout. HQI results were used to identify the flow needed to maintain existing levels of Colorado River cutthroat trout production between July 1 and September 30 (Table 2).

In the HQI analysis, habitat attributes measured at various flow events are assumed to be typical of late summer flow conditions. For example, stream widths measured in June under high flow conditions are considered a fair estimate of the stream width that would occur if the same flow level occurred in the month of September. Under this assumption, HU estimates are extrapolated through a range of potential late summer flows (Conder and Annear 1987). Sage Creek habitat attributes were measured on the same dates PHABSIM data were collected (Table 1). Some attributes were mathematically derived to establish the relationship between discharge and trout habitat at discharges other than those measured.

Average daily flow (ADF; 3.3 cfs) and peak flow (47 cfs) estimates for determining critical period stream flow and annual stream flow variation are based on precipitation and basin area (Lowham 1988). A Ryan temperature recorder monitored water temperature at 4-hour intervals between June 4 and August 26, 1997.

Physical Habitat Simulation

Physical Habitat Simulation (PHABSIM) methodology was used to quantify physical habitat (depth and velocity) availability for life stages over a range of discharges. The methodology was developed by the Instream Flow Service Group of the U.S. Fish and Wildlife Service (Bovee and Milhous 1978) and is widely used for assessing instream flow relationships between fish and physical habitat (Reiser et al. 1989).

The PHABSIM method uses empirical relationships between physical variables (depth, velocity, and substrate) and suitability for fish to derive weighted usable area (WUA; suitable ft^2 per 1,000 ft of stream length) at various flows. Depth, velocity, and substrate were measured along transects (*sensu* Bovee and Milhous 1978) on the dates in Table 1. Hydraulic calibration techniques and modeling options in Milhous et al. (1984) and Milhous et al. (1989) were employed to incrementally estimate physical habitat between 0.3 and 6.0 cfs.

Spawning area as well as physical habitat for other life stages was modeled for the entire reach covered by the ten transects. The spawning simulations were used in developing instream flow recommendations while the remaining simulations were used to validate the recommendations from the Habitat Retention and Habitat Quality Index models and provide incremental analyses of changes in physical habitat with flow.

Habitat suitability curves describing depth, velocity and substrate suitability for trout life stages are an important component of the PHAMSIM modeling process. The spawning suitability curves used for deriving instream flow recommendations are from data collected by Thurow and King (1994) and are listed in Appendix 2. Curves for fry are from Bozek and Rahel (1992) while those for adults and juveniles were developed from bank observations of Colorado River cutthroat trout in Dirtyman Creek, tributary to Savery Creek.

Observations by WGFD biologists indicate spawning activity in Sage Creek likely peaks in May during most years. During site reconnaissance on May 20, 1997, trout were observed near shallow gravel areas suggesting that spawning activity was imminent. Because spawning onset and duration varies between years due to differences in flow quantity and water temperature, spawning flow recommendations should extend from May 1 to June 30 (Table 2). Even if spawning is completed before the end of this period, maintaining flows at a selected level throughout June will benefit trout egg incubation by preventing dewatering.

RESULTS AND DISCUSSION

Trout populations are naturally limited by extreme conditions during the winter months (October through March; Needham et al. 1945, Reimers 1957, Butler 1979, Kurtz 1980, Cunjak 1988, Cunjak 1996, Annear et al. *In Press*). Frazil ice (suspended ice crystals formed when water is chilled below 0°C) in high gradient stream reaches can be both a direct mortality source through gill abrasion and subsequent suffocation or an indirect mortality source when resultant anchor ice limits habitat, causes localized de-watering, and exerts excessive metabolic demands on fish forced to seek ice-free habitats (Brown et. al 1994). Pools downstream from high gradient frazil ice-forming areas can accumulate anchor ice when woody debris or surface ice provides anchor points for frazil crystals (Brown et. al 1994, Cunjak and Caissie 1994). Such accumulations may result in mortalities if low winter flows or ice dams block emigration.

Super-cooled water (<0° C) can also physiologically stress fish. As temperatures decrease below 4° C, fish gradually lose ion exchange abilities. At water temperatures near 0° C, fish have limited ability to assimilate oxygen or rid cells of carbon dioxide and other waste products. If fish are forced to be active near 0°C, such as to avoid frazil ice, direct mortalities can occur. The extent of impacts depends on the magnitude, frequency and duration of frazil events and the availability of escape habitats (Jakober et al. 1998). Juvenile and fry life stages tend to be impacted more than larger fish because younger fish inhabit shallower habitats and stream margins where frazil ice accumulates. Larger fish that inhabit deep pools may endure frazil events if they are not displaced.

Refuge from frazil ice occurs in groundwater influx areas, ice covered pools not close to frazil ice sources, and where heavy snow cover and stream bridging reduces frazil formation (Brown et al. 1994). Lower gradient streams and narrow streams are more likely to have insulating surface ice cover or at higher elevations, heavy snow cover and bridging. Sage Creek's high elevation, relatively narrow width and moderate slope suggest that snow bridging occurs in the headwaters. Frazil ice formation may be a concern low in the instream flow segment mainly in early winter before sufficient insulating snow is present or in late winter when snow melt becomes superchilled by flowing over snow and ice before entering the stream. Near the downstream end of the segment, extensive surface ice was noted November 16, 1990 (WGFD 1991). Because of uncertainties about winter conditions, natural winter flow levels up to the identified 1.1 cfs should be maintained to maximize access to and availability of frazil-ice-free refugia. Any artificial reduction of natural winter stream flows could increase trout mortality, reduce the number of fish the stream could support, and degrade the existing fishery.

Habitat Retention Analysis

Maintenance of naturally occurring flows up to 1.1 cfs is necessary at all times of the year (Table 4). All three attributes assessed with the Habitat Retention method (depth, velocity, and wetted perimeter) played a role in defining a winter flow recommendation. At flows lower than 1.1 cfs, values for these parameters fall below the designated levels and conditions become unsuitable for trout.

The 1.1 cfs identified by the Habitat Retention Method may not always be present during the winter. Because the existing fishery is adapted to natural flow patterns, occasional shortfalls during the winter do not imply any degree of infeasibility or a need for additional storage. Instead, they illustrate the necessity of maintaining all natural winter stream flows, up to 1.1 cfs, to maintain existing trout survival rates.

Habitat Unit Analysis

Article 10, Section d of the Instream Flow Act states that waters used for providing instream flows "shall be the minimum flow necessary to maintain or improve existing fisheries". One way to define "existing fishery" is by the number of habitat units that occur under normal July through September flow conditions. Since there is no stream flow gage on Sage Creek, an estimate for discharge over the July through September period can be derived from the two flows measured in late summer 1997 (Table 1). A reasonable estimate of late summer flow in Sage Creek is thus somewhere around 1.1 to 1.2 cfs. This level of flow provides about 33 habitat units (Figure 3). To maintain 33 trout habitat units, the simulation shows that flows of 0.9 cfs to 1.3 cfs are needed. For the purpose of maintaining existing fishery values, the term "minimum" means the lowest amount of flow that will provide the identified fishery benefits, whenever it is naturally available. Therefore, the minimum flow to maintain the existing fishery during late summer is 0.9 cfs.

Based on this analysis, an instream flow of 0.9 cfs between July 1 and September 30 would maintain existing trout habitat quality. The habitat retention analysis has already shown that a slightly higher flow of 1.1 cfs is necessary to maintain hydraulic criteria at riffles. Therefore, the recommendation for the late summer period is 1.1 cfs. The existing fishery is naturally dynamic as a function of stream flow availability. In years when stream flow is naturally less than 1.1 cfs in late summer the fishery can be expected to decline. Likewise, in years when late summer flow is 1.1 cfs or more, it should expand. Maintaining this existing fishery simply means maintaining existing natural stream flows up to the recommended amount in order to maintain the natural habitat and fish population fluctuations.

Table 4. Simulated hydraulic criteria for three Sage Creek riffles. Average daily flow = 3.3 cfs. Bank full discharge = 47 cfs

	Mean Depth (ft)	Mean Velocity (ft/s)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1	0.80	2.16	13.0	21
	0.52	**1.01**[a]	10.1	5.0
	0.46	0.77	9.3	3.1
	0.42	0.62	8.7	2.1
	0.39	0.55	8.5	1.7
	0.37	0.51	8.4	1.5
	0.36	0.49	8.3	1.4
	0.32	0.40	8.1	1.0
	0.21[a]	0.21	7.1	**0.3**[b]
	<0.21	<0.21	**<7.1**[a]	<0.3
Riffle 2	0.55	2.36	16.9	21
	0.27	1.81	10.6	5.0
	0.23	1.67	**8.4**[a]	3.1
	0.21	1.55	6.8	2.1
	0.20	1.48	6.1	1.7
	0.20	1.23	6.3	1.5
	0.20	1.18	6.2	1.4
	0.20	**1.01**[a]	5.8	**1.1**[b]
	0.20[a]	0.89	5.5	0.9
	0.19	0.83	5.3	0.8
Riffle 3	0.55	3.53	11.2	21
	0.32	1.70	9.3	5.0
	0.27	1.35	8.6	3.1
	0.26	1.12	7.5	2.1
	0.24	**1.01**[a]	7.2	1.7
	0.23	0.95	7.1	1.5
	0.22	0.92	7.1	1.4
	0.20[a]	0.82	7.0	**1.1**[b]
	0.19	0.74	6.4	0.9
	0.16	0.55	**5.6**[a]	0.5

a - Hydraulic criteria met
b - Discharge at which 2 of 3 hydraulic criteria are met

PHABSIM Analyses

The spawning life stage was identified as important for maintaining CRC populations in Sage Creek. The amount of physical area available for spawning in the study site peaked at a flow of 3.9 cfs and declined rapidly at higher flow levels (Figure 4). Therefore, the instream flow recommendation to maintain spawning habitat for the period of May 1 to June 30 is 3.9 cfs.

Physical habitat levels for adults, juveniles and fry do not change drastically as a function of flow in Sage Creek (Figure 5). The recommended winter flow of 1.1 cfs from Habitat Retention appears to offer relatively high weighted useable area for all life stages.

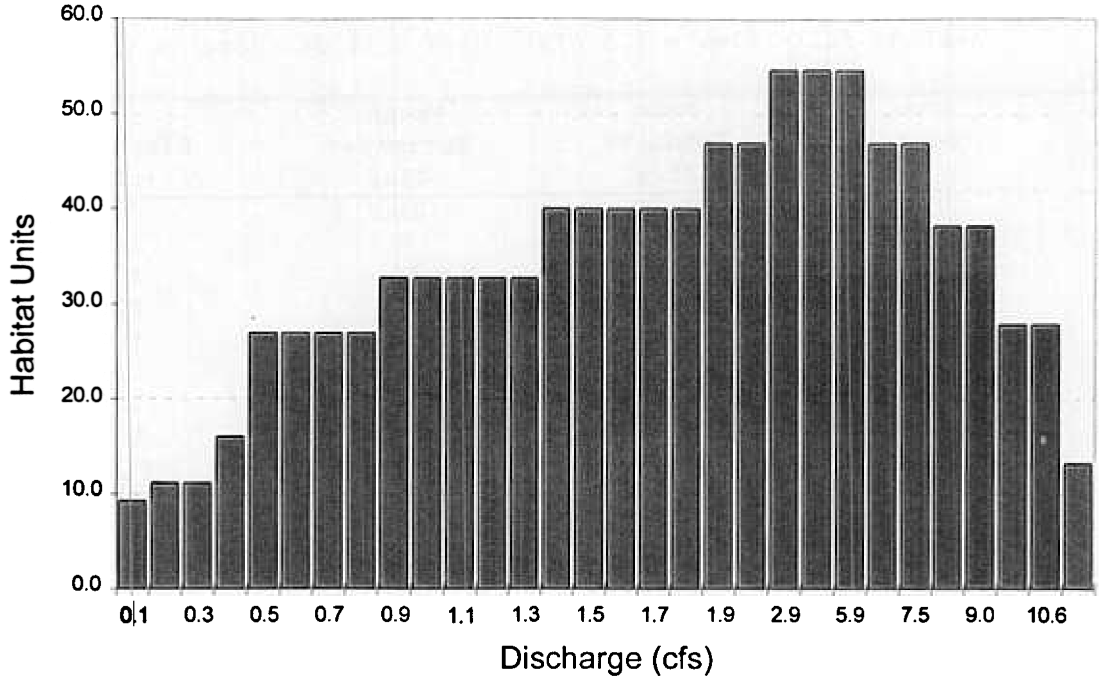

Figure 3. Trout habitat units at several late summer Sage Creek flow levels. X-axis discharges are not to scale.

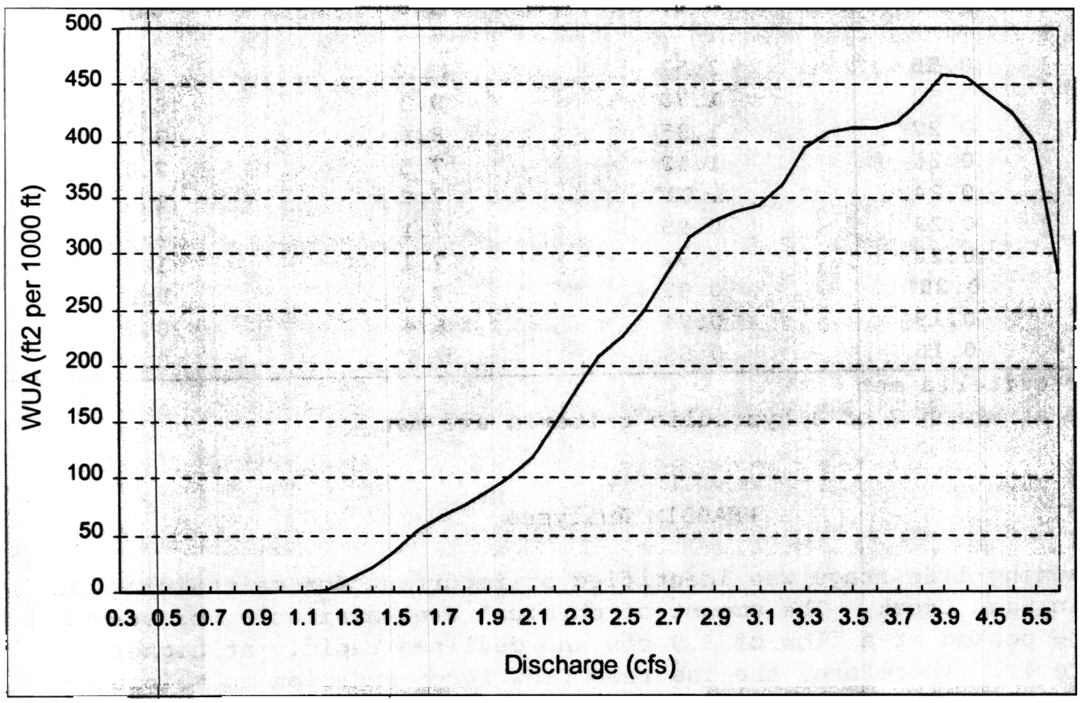

Figure 4. Relationship between stream flow and spawning habitat at a Sage Creek study site.

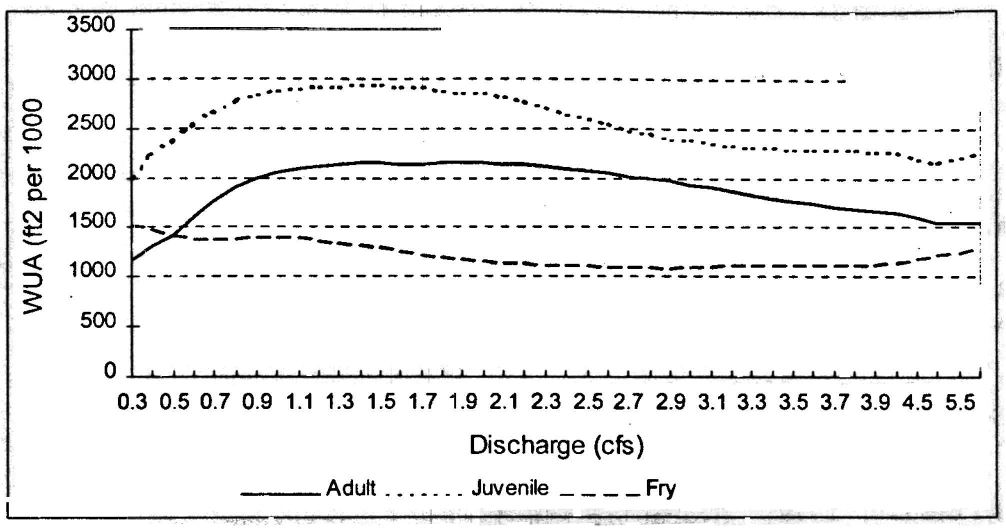

Figure 5. Weighted usable area for Colorado River cutthroat trout in Sage Creek over a range of discharges. X-axis discharges are not to scale.

INSTREAM FLOW RECOMMENDATIONS

Based on the analyses and results outlined above, the instream flow recommendations in Table 5 will maintain the existing Sage Creek Colorado River cutthroat trout fishery. These recommendations apply to an approximately 4 mile Sage Creek segment extending downstream from the boundary between sections 12 and 13 of Range 115W, Township 12N. The downstream boundary for the proposed instream flow segment is the Forest Service boundary in section 31 of Range 114W, Township 13N. The land through which the proposed segment passes is under Forest Service administration. Because data were collected from representative habitats and simulated over a wide flow range, additional data collection under different flow conditions would not significantly change these recommendations.

Table 5. Instream flow recommendations to maintain the existing Sage Creek trout fishery.

Time Period	Instream Flow Recommendation (cfs)
October 1 to April 30	1.1
May 1 to June 30	3.9
July 1 to September 30	1.1

This analysis does not consider periodic requirements for channel maintenance flows. Because this stream is unregulated, channel maintenance flow needs are adequately met by natural runoff patterns. If regulated in the future, additional studies and recommendations will be needed for establishing channel maintenance flow requirements.

LITERATURE CITED

Annear, T.C. and A.L. Conder. 1984. Relative bias of several fisheries instream flow methods North American Journal of Fisheries Management 4:531-539.

Annear, T. C., W. Hubert, D. Simpkins and L. Hebdon. In Press. Behavioral and physiological response of trout to winter habitat in Wyoming, USA. Hydrological Processes.

Binns, N.A. 1982. Habitat Quality Index Procedures Manual WDFG Publication

Binns, N.A. and F. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108:215-228.

Bovee, K. and R. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and technique. Instream Flow Information Paper 5, FWS/OBS-78/33, Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service. Fort Collins, Colorado.

Bozek, M.A. and F.J. Rahel. 1992. Generality of microhabitat suitability models of young Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) across site and among years in Wyoming streams. Canadian Journal of Fisheries and Aquatic Science 49:552-564.

Brown, R.S., S.S. Stanislawski, and W.C. Mackay. 1994. Effects of frazil ice on fish. *In* Proceedings of the Workshop on the Environmental Aspects of River Ice, Saskatoon, Sask., 18-20 August 1993. *Edited by* T.D Prowse. NHRI Symp. Ser. No.12. National Hydrology Research Institute, Saskatoon, Sask. pp.261-278.

Butler, R. 1979. Anchor ice, its formation and effects on aquatic life Science in Agriculture, Vol XXVI, Number 2, Winter, 1979.

Conder, A.L. and T.C. Annear. 1987. Test of weighted usable area estimates derived from a PHABSIM model for instream flow studies on trout streams. North American Journal of Fisheries Management 7:339-350.

Cunjak, R.A. 1988. Physiological consequences of overwintering in streams; the cost of acclimatization? Canadian Journal of Fisheries and Aquatic Sciences 45:443-452.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of fisheries and Aquatic Sciences 53(Suppl.1):267-282.

Cunjak, R.A. and D. Caissie. 1994. Frazil ice accumulation in a large salmon pool in the Miramichi River, New Brunswick: ecological implications for overwintering fishes. *In* Proceedings of the Workshop on the Environmental Aspects of River Ice, Saskatoon, Sask., 18-20 August 1993. *Edited by* T.D. Prowse. NHRI Symp. Ser. No.12. National Hydrology Research Institute, Saskatoon, Sask. pp.261-278.

House, R. 1995. Temporal variation in abundance of an isolated population of cutthroat trout in western Oregon, 1981-1991. North American Journal of Fisheries Management 15:33-41.

Jakober, M.E., T.E. McMahon, R.F. Thurow, and C.G. Clancy. 1998. Role of stream ice on Fall and Winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society 127:223-235.

Keith, R. 1997. Green River Basin Management Plans. Basin Management Plan - Smiths Fork River (3SF). Wyoming Game and Fish Department, Green River, WY.

Kurtz, J. 1980. Fishery management investigations. - a study of the upper Green River fishery, Sublette County, Wyoming (1975-1979). Completion Report. Wyoming Game and Fish Department, Fish Division Cheyenne.

Lowham, H.W. 1988. Streamflows in Wyoming USGS Water Resources Investigations Report 88-4045.

Milhous, R.T., D.L. Wegner, and T. Waddle. 1984. User's guide to the physical habitat simulation system. Instream Flow Paper 11, FWS/OBS 81/43, U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Milhous, R.T., M.A. Updike, and D.M. Schneider. 1989. Physical habitat simulation system reference manual - version II. Instream Flow Information Paper No. 26. U.S. Fish and Wildlife Service, Biol. Rep. 89(16).

Mueller, J.W. 1987. Electrofishing results in Sand Creek, Hospital Gulch Station, Sand Creek Country Club, 1986. Wyoming Game and Fish Department Administrative Report.

Needham, P., J. Moffett, and D. Slater. 1945. Fluctuations in wild brown trout populations in Convict Creek, California. Journal of Wildlife Management 9:9-25.

Nehring, R. 1979. Evaluation of instream flow methods and determination of water quantity needs for streams in the state of Colorado. Colorado Division of Wildlife, Fort Collins.

Nehring, B.R. and R.M. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation System. Rivers 4:1-19.

Nesler, T., M. McAfee, R. Remmick, B. Rosenblund, and R. Radant. 1999. Draft conservation agreement and strategy for Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) in the states of Colorado, Utah, and Wyoming.

Reimers, N. 1957. Some aspects of the relation between stream foods and trout survival. California Fish and Game 43:43-69.

Reiser, D.W., T.A. Wesche, and C. Estes. 1989. Status of instream flow legislation and practices in North America. Fisheries 14(2):22-29

Rosgen, D. and L. Silvey. 1998. Field guide for stream classification Wildland Hydrology, Pagosa Springs, CO.

Thurow, R.F. and J.G. King. 1994. Attributes of Yellowstone cutthroat trout redds in a tributary of the Snake River, Idaho. Transactions of the American Fisheries Society 123:37-50.

WGFD. 1991. Annual fisheries progress report on the 1990 annual work schedule 433 pages. Wyoming Game and Fish Department, Cheyenne, WY.

Young, M.K., N.R. Schmal, T.W. Kohley, and V.G. Leonard. 1996. Conservation status of Colorado River cutthroat trout. General Technical Report RM-GTR-282. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky mountain Forest and Range Experiment Station. 32 p.

Appendix 1   Reach weighting used for PHABSIM analysis

Transect	Reach Length (ft)	Percent	Habitat Type
1	1.8	2.0	Riffle/Spawn/Habitat Retention
2	3.6	4.0	Run
3	3.1	3.5	Pool
4	28.5	31.9	Fast riffle
5	1.2	1.3	Riffle/Spawn/Habitat Retention
6	11.2	12.5	Pool
7	9.7	10.9	Wide run
8	14.5	16.2	Riffle/Spawn/Habitat Retention
9	11.1	12.5	Run
10	4.6	5.2	Deep Run/pool

Appendix 2. Spawning suitability index data used in PHABSIM analysis. Index data are from Thurow and King, 1994.

Velocity	Weight	Depth	Weight	Substrate	Weight